

## EVALUATION OF TWO COMMERCIAL TRAPS FOR THE COLLECTION OF *CULICOIDES* (DIPTERA: CERATOPOGONIDAE)

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**ABSTRACT.** Two types of commercial propane-powered traps, mosquito magnet (MM) (American Biophysics Corporation) MM-Freedom® (Freedom) and MM-Liberty Plus® (Liberty Plus), were evaluated for the collection of *Culicoides*. Trap preference and seasonal characteristics for the 3 major species, *Culicoides furens*, *Culicoides barbosai*, and *Culicoides mississippiensis*, were recorded from July 7, 2005, to July 24, 2006. Over 35 million *Culicoides* were captured during our study. When species were evaluated separately, analysis of overall mean trap collections yielded 5 months (February, March, June, September, and October) with significant trap effects. The Freedom trap captured more *C. furens* in June and October; the Liberty Plus trap captured more *C. mississippiensis* in February, March, and April, and more *C. barbosai* in September. The high numbers of *Culicoides* captured during our study suggest that the number of host-seeking *Culicoides* could potentially be reduced by continuous trapping during times when they are prevalent. Results of these investigations will be used to guide future control efforts.

**KEY WORDS** Diptera, Ceratopogonidae, *Culicoides*, commercial traps

### INTRODUCTION

Hematophagous biting midges in the genus *Culicoides* (Diptera: Ceratopogonidae) are a severe nuisance to humans and domestic animals (Lysyk 2006). In coastal areas, *Culicoides* attack in such great numbers that they are often unbearable to residents and tourists (Cilek et al. 2003). They interfere with recreational activities such as fishing, golf, hunting, swimming, and tennis (Kline 1975). Tourists are intolerant when on vacation and may prematurely end their vacations because of *Culicoides* biting alone, compromising the economic stability of hotels or resorts. Linley and Davies (1971) estimated that most vacationing tourists can tolerate up to 5 bites per hour.

*Culicoides* also have a negative impact on the real estate industry. In the town of Hervey Bay, Queensland, Australia, it is estimated that *Culicoides* cause \$25–\$55 million gross reduction to the real estate industry (Ratnayake et al. 2006). Potential problems with *Culicoides* populations have to be taken into consideration when developing land, specifically near salt marshes or mangrove swamps (Linley and Davies 1971).

Previous studies have shown that *Culicoides* habitat manipulation and larviciding are the most effective long-term control methods (Goulding et al. 1953, Labrecque 1954, Blanton et al. 1955, Rogers 1962, MacLaren et al. 1967, Altman et al. 1970, Wall and Marganian 1971). However, reduction of *Culicoides* populations through larval control by the application of insecticides

to the soil or physical modification of wetland developmental sites is no longer an option in Florida because of state and federal environmental regulatory issues (Cilek et al. 2003). Repellents only provide minimal and temporary relief and are not considered a long-term solution (Schreck and Kline 1981, Trigg 1996, Carpenter et al. 2005). New techniques are needed if *Culicoides* populations are to be managed efficiently.

Adult trapping is being investigated as a potential control method for anthropophilic insects in some parts of the United States. An increase in public pressure to reduce pesticide use has sparked an interest in this method (Day and Sjogren 1994). Adult removal trapping is not a new technique; however, recently there has been considerable improvement in adult trap technology. Kline and Lemire (1998) demonstrated that a single line barrier of attractant-baited CDC-type traps reduced mosquito populations on a barrier island resort in southwest Florida.

Cilek et al. (2003) and Cilek and Hallmon (2005) attempted to reduce *Culicoides* populations around homes in Florida using 1 Mosquito Magnet® Pro (American Biophysics Corporation, North Kingston, RI) trap per backyard. They concluded that 1 trap per backyard was not sufficient for *Culicoides* reduction. It was suggested that using more than 1 trap per backyard, or a perimeter of traps, may be the key to consistent reduction of the *Culicoides* population. A mass trapping program against *Culicoides* on an island in the Bahamas resulted in a significant reduction in the number of *Culicoides* throughout the island (Day et al. 2001).

It is not clear which adult trap would be best for population suppression of *Culicoides*. Therefore, the objective of this study was to compare 2 commercially available attractant-baited mosquito traps on the island of Rye Key in Cedar Key,

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Fig. 1. Aerial image of study sites in Cedar Key, FL. (A) Rye Key. (B) 2×2 study site.

FL, to determine which model is more successful at capturing *Culicoides* spp. Trap efficiency and seasonality characteristics for the 3 major species, *Culicoides furens* (Poey), *Culicoides barbosai* Wirth and Blanton, and *Culicoides mississippiensis* Hoffman, were evaluated.

## MATERIALS AND METHODS

**Study site:** Cedar Key (29.12 N, –83.08 W) is located on a group of islands in Levy County, FL, 6.44 km offshore in the Gulf of Mexico and accessible by bridges and causeways. Rye Key is a 5.91-ha island located at the northeast tip of Cedar Key (Fig. 1). This site was chosen because of previously documented, abundant *Culicoides* populations (Kline, unpublished data). An electronic gate provides limited access on Rye Key, thus reducing the chances of vandalism or theft of research equipment. The surrounding salt marsh located at Rye Key consists predominately of rush (*Juncus* spp.) and cordgrass (*Spartina* spp.).

**Trap types:** The 2 mosquito magnet trap models used in this study were donated by the American Biophysics Corporation. The MM-Freedom® (Freedom) trap (Fig. 2A) is a propane-powered, counterflow geometry trap as described by Kline (2002) and Cooperband and Cardé (2006). This trap consists of a plastic

housing that encapsulates a metal power pack where the catalytic combustion of propane occurs. The power pack and plastic housing are supported by a metal frame. Two fans are mounted inside the power pack to create the counterflow. A small fan delivers the plume of attractants via a small, black, polyvinyl chloride (PVC) tube, while a larger fan pulls the insects into a fine mesh collection net via a larger black PVC tube located inside the plastic housing. The trap is baited with a 1-octen-3-ol (octenol) cartridge (American Biophysics), approximately 420 ml/min of CO<sub>2</sub>, heat, and moisture. Propane is supplied by a standard 9.07-kg commercial tank, and its combustion produces CO<sub>2</sub>, heat, and moisture, which act as attractants. The plume temperature for this trap ranges from 33.34°C to 36.67°C (K. McKenzie, personal communication).

The MM-Liberty Plus® (Liberty Plus) trap (Fig. 2B) is also a propane-powered, counterflow geometry trap similar to the Freedom trap. This trap is comprised of a plastic housing that encapsulates a hybrid power system containing a thermoelectric module and a nickel metal hydride battery pack. The hybrid power system is fueled by propane. The plastic housing is supported by a plastic stand. Two fans are mounted inside the hybrid power system to create

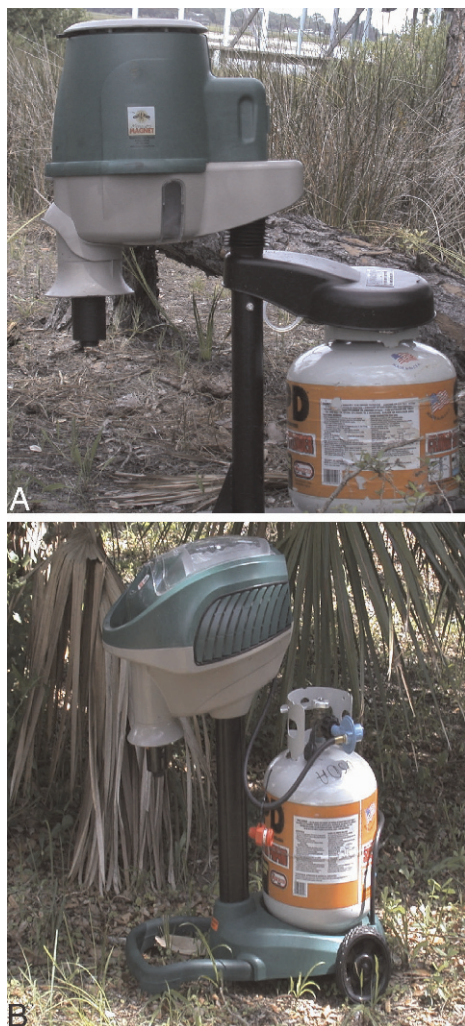


Fig. 2. Two models of mosquito magnet traps used in the study conducted in Rye Key, FL. (A) Freedom®. (B) Liberty Plus®. Traps were baited with octenol, CO<sub>2</sub>, and heat.

the counterflow. A small fan delivers the plume of attractants through a small cast aluminum tube, while a larger fan pulls the insects into a fine mesh collection net located inside the plastic housing. The trap is baited with a 1-octen-3-ol (octenol) cartridge, approximately 550 ml/min CO<sub>2</sub>, heat, and moisture. Propane is supplied by a standard 9.07-kg commercial propane tank. The plume temperature ranges from 33.34°C to 40.56°C (K. McKenzie, personal communication). The Liberty Plus has a push-button start and lights that indicate when the machine is operating and whether service is needed.

**Trap comparison study:** Ten Freedom and 6 Liberty Plus traps were placed on Rye Key. Each trap was placed in the center of a 0.30- to 0.40-ha

area and remained in its location throughout the entire study. The study was conducted from July 7, 2005, to July 24, 2006. The collection net from each trap was replaced 1–2 times per week throughout the study. Propane tanks were changed every 18 days while the traps were in operation, and octenol cartridges were changed every 21 days.

All collection nets removed from traps were placed individually into 3.78-liter plastic resealable bags, and all insects inside the traps but outside the nets were vacuumed and placed inside the plastic bag. Each plastic bag was labeled and transported to the laboratory under ambient conditions. Any trap that malfunctioned was replaced immediately, and all Freedom power packs were replaced after 6 months to maintain trap quality.

Upon returning to the laboratory, all collections were immediately placed in a cold room (5°C) to immobilize the insects. Once immobile, insects were transferred into either 237- or 473-ml paper food cartons, labeled, and stored in a –20°C freezer. During processing, *Culicoides* were separated from nontarget insects using a 16-mesh copper screen. If the number of *Culicoides* captured was estimated to be more than 500, an aliquot was extrapolated from the total capture and weighed. The weight of the aliquot was divided into the total weight of the sample, and the quotient was multiplied by the number of *Culicoides* of each species that were identified and counted in the aliquot. If the number of *Culicoides* was estimated to be below 500, the entire collection was identified and counted. During the 13 months that the traps were operated on Rye Key, FL, the seasonal abundance of the 3 major *Culicoides* species was evaluated.

Because trap collections were generally made twice weekly, trap collections represented different numbers of days. Prior to analysis, trap collections were divided by the number of days in the collection interval, so that all values represented the average number of *Culicoides* collected per day. These data were used to calculate an estimated daily mean value for the total and individual species of *Culicoides* collected each month. The trap and month variables were fixed effects. Data were subjected to a log ( $x + 1$ ) transformation then analyzed using 2-way analysis of variance (ANOVA) with trapping period (month) and trap type as independent variables in the model (PROC GLM; SAS Institute 1999). Means were separated with the Ryan-Einot-Gabriel-Welsch multiple range test. Untransformed means are presented in all tables. Trap comparison data from the Rye Key study site were compared by month to determine seasonal trends among major species. Trap collections were again divided by the numbers of days of

Table 1. Total *Culicoides* captured by 2 types of traps in Cedar Key, FL, from July 7, 2005, to July 24, 2006.

Trap	No. traps	No. trap nights	Total
Freedom	10	3,641	23,109,389
Liberty Plus	6	2,112	12,048,806
Total	16	5,753	35,158,195

collection so that all values represented the average number of *Culicoides* collected per day. Then these data were used to calculate a daily mean value per week for each *Culicoides* species. Log ( $x + 1$ ) transformed values were used to plot seasonal abundance graphs.

**Trap comparison-position effect:** On an undeveloped lot in a residential neighborhood on the north end of Cedar Key (Fig. 1), an analysis was conducted comparing Freedom and Liberty Plus traps, position of the traps, and the trap type by position interaction. The traps were operated as previously described. The selected site was 1.61 km from the Rye Key trap site. Traps were placed on adjoining 0.40-ha lots, between a wooded tree line and a salt marsh. The salt marsh was predominated by rush (*Juncus* spp.) and cordgrass (*Spartina* spp.). This study was timed to coincide with the expected abundance of the 2 major *Culicoides* species for this area, *C. mississippiensis* and *C. furens* (Blanton and Wirth 1979).

Two positions within the selected site were chosen for trap placement. One Freedom and 1 Liberty Plus trap were each assigned randomly to a position. After each trapping period (1 to 4 d), the traps were rotated to the opposite position. This study consisted of 4 separate trapping periods in January 2006 and 2 trapping periods in both March and April 2006. For each trapping period, both traps were in their respective positions for an equal amount of time. The collected specimens were processed as previously described. Trap collections were generally made twice weekly during 4 weeks in January 2006 and again in March–April 2006. To determine whether a position effect existed with these traps, data were analyzed by using a Latin square design (PROC ANOVA) with trap, position, and trap by replicate interactions included in the model (SAS Institute 1999). Data were subjected to a log ( $x + 1$ ) transformation prior to analysis.

## RESULTS

**Trap comparison study:** A total of 35,158,195 female *Culicoides* were collected in 16 traps during the 13-month field study at Cedar Key (Table 1). There were 6 *Culicoides* species captured; however, only 3 of the 6 species (*C. furens*, *C. mississippiensis*, and *C. barbosai*) were abundant enough to be analyzed statistically. *Culicoides*

Table 2. Prevalence of *Culicoides* species caught by 10 Freedom® and 6 Liberty Plus® traps in Cedar Key, FL, from July 7, 2005, to July 24, 2006.

Species	No. <i>Culicoides</i> spp. captured	% total <i>Culicoides</i> captured
<i>Culicoides furens</i>	32,208,267	91.6
<i>Culicoides mississippiensis</i>	1,978,099	5.6
<i>Culicoides barbosai</i>	971,829	2.8
Total	35,158,195	100.0

*des furens*, which represented 91.6% of the total catch, was the most abundant species collected (Table 2). Next was *C. mississippiensis* (5.6%), followed by *C. barbosai* (2.8%). Other *Culicoides* species captured in much smaller numbers included *Culicoides melleus* (Coquillett), *Culicoides insignis* (Lutz), and *Culicoides debilipalpis* (Lutz).

***Culicoides furens*:** The overall mean daily collection of *C. furens* in Freedom traps was significantly higher than the number collected in the Liberty Plus traps ( $F = 6.5$ ;  $df = 1, 104$ ;  $P = 0.0106$ ). When data were analyzed by month, the Freedom traps captured significantly more ( $F = 308.18$ ;  $df = 12, 156$ ;  $P < 0.0001$ ) *C. furens* in October 2005 and June 2006 than did the Liberty Plus traps (Table 3). The trap by month interaction was significant ( $F = 2.21$ ;  $df = 12, 22$ ;  $P = 0.0122$ ).

***Culicoides barbosai*:** The overall mean daily collection of *C. barbosai* in Freedom and Liberty Plus traps from July 7, 2005, to July 24, 2006, were not significantly different ( $F = 0.08$ ;  $df = 1, 104$ ;  $P = 0.782$ ). However, the Freedom traps collected significantly more ( $F = 93.1$ ;  $df = 12, 156$ ;  $P < 0.0001$ ) *C. barbosai* in September 2005 than did the Liberty Plus traps (Table 4). The trap by month interaction was significant ( $F = 2.55$ ;  $df = 12, 22$ ;  $P = 0.003$ ).

***Culicoides mississippiensis*:** The overall mean daily collection of *C. mississippiensis* in Liberty Plus traps was significantly higher ( $F = 26.9$ ;  $df = 1, 104$ ;  $P < 0.0001$ ) than that captured in the Freedom traps from July 7, 2005, to July 24, 2006. When data were analyzed by month, the Liberty Plus traps captured significantly more ( $F = 171.67$ ;  $df = 12, 156$ ;  $P < 0.0001$ ) *C. mississippiensis* in February, March, and April 2006 than did the Freedom traps (Table 5). The trap by month interaction was not significant ( $F = 1.69$ ;  $df = 12, 22$ ;  $P = 0.071$ ).

**Seasonal abundance:** Seasonal abundance patterns of *C. furens* and *C. barbosai* collected by both traps followed similar trends (Figs. 3 and 4). *Culicoides furens* and *C. barbosai* were prevalent in the warmer months from late May through October and then declined in November. *Culicoides mississippiensis* was captured in small num-

Table 3. Daily collection means by month of *Culicoides furens* captured in 10 Freedom® and 6 Liberty Plus® traps placed in the Rye Key neighborhood on Cedar Key, FL, from July 7, 2005, to July 24, 2006.

Month <sup>1</sup>	Freedom			Liberty Plus			df
	<i>n</i>	Trap nights	Mean ± SE	<i>n</i>	Trap nights	Mean ± SE	
5-Jul	71	260	11,202 ± 3,114 abc	40	148	9,643 ± 3,686 ab	109
Aug	89	300	18,277 ± 4,229 abc	53	177	17,588 ± 6,192 ab	140
Sept	89	300	5,649 ± 1,371 c	54	180	11,608 ± 3,860 ab	141
Oct*	90	310	8,998 ± 2,192 bc	53	186	2,141 ± 748 b	142
Nov	69	265	610 ± 246 d	40	154	454 ± 134 c	108
Dec	69	310	2.85 ± 0.68 f	40	170	1.6 ± 0.56 e	108
6-Jan	71	250	0.21 ± 0.08 f	38	124	2.4 ± 2.01 e	104
Feb	58	239	0.04 ± 0.04 f	38	122	0 ± 0 e	94
Mar	60	310	68.17 ± 25.49 e	36	186	100 ± 46 d	94
Apr	40	280	2,206 ± 437 bc	24	168	2,328 ± 731 ab	62
May	40	280	7,988 ± 1,887 ab	24	168	10,984 ± 2,515 a	62
Jun*	48	300	13,824 ± 2,973 a	30	180	3,065 ± 811 ab	76
Jul	18	162	8,990 ± 2,839 a	11	101	6,488 ± 3,778 ab	27

<sup>1</sup> Within a row, months followed by an asterisk designate significant difference between trap collection means ( $\alpha = 0.05$ ). Within a column, means followed by the same letter are not significantly different, Ryan-Einot-Gabriel-Welsch multiple range test ( $\alpha = 0.05$ ). *n* = the number of trap replicates for the corresponding month. The value *n* varies according to number of traps and successful trap nights. Within a column, degree of freedom for error within each month is denoted by df; trap df = 1

bers throughout the year but was more prevalent during the cooler months from November through May (Fig. 5).

**Trap comparison-position effect:** The trap comparison-position effect was conducted in January when *C. mississippiensis* was the dominant species and during a period in March and April when *C. furens* was the dominant species. A total of 37,014 *Culicoides* were captured during the trap comparison-position trial. The Freedom trap captured 18,962 *Culicoides*, and the Liberty Plus captured 18,052. Small numbers of *C. barbosa* were collected, but *C. furens* and *C.*

*mississippiensis* were the only species collected in numbers high enough to analyze. There were no significant differences between trap type ( $F = 0.1$ ,  $df = 1$ ,  $P = 0.7688$ ) or trap positions ( $F = 0.22$ ,  $df = 1$ ,  $P = 0.6607$ ) for *C. furens*; trap by position interaction was not significant ( $F = 5.85$ ,  $df = 1$ ,  $P = 0.0729$ ). There were no significant differences between trap type ( $F = 0.00$ ,  $df = 1$ ,  $P = 0.9962$ ) or trap positions ( $F = 0.00$ ,  $df = 1$ ,  $P = 0.9904$ ) for *C. mississippiensis*; trap by position interaction was not significant ( $F = 0.33$ ,  $df = 1$ ,  $P = 0.5987$ ). These findings agree with the observations recorded for the larger Rye Key study site.

Table 4. Daily collection means by month of *Culicoides barbosa* captured in 10 Freedom® and 6 Liberty Plus® traps placed in the Rye Key neighborhood on Cedar Key, FL, from July 7, 2005, to July 24, 2006.

Month <sup>1</sup>	Freedom			Liberty Plus			df
	<i>n</i>	Trap nights	Mean ± SE	<i>n</i>	Trap nights	Mean ± SE	
5-Jul	71	260	396 ± 56.91 a	40	148	321 ± 74.61 a	109
Aug	89	300	162 ± 42.35 cd	53	177	86.41 ± 19.58 bc	140
Sep*	89	300	190 ± 51.91 cd	54	180	669 ± 236 a	141
Oct	90	310	443 ± 75.30 ab	53	186	279 ± 88.35 ab	142
Nov	69	265	54.63 ± 11.03 cd	40	154	89.34 ± 22.88 abc	108
Dec	69	310	0.17 ± 0.07 e	40	170	0.32 ± 0.23 d	108
6-Jan	71	250	0 ± 0 e	38	124	0.01 ± 0.01 d	104
Feb	58	239	0 ± 0 e	38	122	0 ± 0 d	94
Mar	60	310	1.84 ± 1.11 e	36	186	2.78 ± 1.36 d	94
Apr	40	280	56.16 ± 17.40 d	24	168	26.69 ± 8.55 c	62
May	40	280	278 ± 70.43 cd	24	168	444 ± 170 a	62
Jun	48	300	278 ± 73.40 bc	30	180	143 ± 33.79 ab	76
Jul	18	162	374 ± 154 a	11	101	294 ± 117 ab	27

<sup>1</sup> Within a row, months followed by an asterisk designate significant difference between trap collection means ( $\alpha = 0.05$ ). Within a column, means followed by the same letter are not significantly different, Ryan-Einot-Gabriel-Welsch multiple range test ( $\alpha = 0.05$ ). *n* = the number of trap replicates for the corresponding month. The value *n* varies according to number of traps and successful trap nights. Within a column, degree of freedom for error within each month is denoted by df; trap df = 1.

Table 5. Daily collection means by month of *Culicoides mississippiensis* captured in 10 Freedom<sup>®</sup> and 6 Liberty Plus<sup>®</sup> traps placed at Cedar Key, FL, from July 7, 2005, to July 24, 2006.

Month <sup>1</sup>	Freedom			Liberty Plus			df
	<i>n</i>	Trap nights	Mean ± SE	<i>n</i>	Trap nights	Mean ± SE	
5-Jul	71	260	18.59 ± 13.98 e	40	148	8.81 ± 4.61 e	109
Aug	89	300	5.58 ± 4.04 e	53	177	33.61 ± 19.33 e	140
Sep	89	300	6.83 ± 3.13 e	54	180	22.53 ± 12.7 e	141
Oct	90	310	223 ± 38.86 d	53	186	213 ± 59.41 c	142
Nov	69	265	714 ± 111 a	40	154	1,181 ± 332 ab	108
Dec	69	310	142 ± 25.17 cd	40	170	348 ± 94.36 bc	108
6-Jan	71	250	388 ± 176 bc	38	124	920 ± 333 ab	104
Feb*	58	239	342 ± 101 abc	38	122	1,296 ± 513 ab	94
Mar*	60	310	404 ± 56.13 ab	36	186	868 ± 104 a	94
Apr*	40	280	362 ± 74.17 abc	24	168	891 ± 157 a	62
May	40	280	610 ± 70.43 c	24	168	883 ± 209 ab	62
Jun	48	300	81.08 ± 60.13 e	30	180	62.07 ± 23.93 d	76
Jul	18	162	5.72 ± 3.26 e	11	101	25.94 ± 17.14 de	27

<sup>1</sup> Within a row, months followed by an asterisk designate significant difference between trap collection means (alpha = 0.05). Within a column, means followed by the same letter are not significantly different, Ryan-Einot-Gabriel-Welsch multiple range test (alpha = 0.05). *n* = the number of trap replicates for the corresponding month. The value *n* varies according to number of traps and successful trap nights. Within a column, degree of freedom for error within each month is denoted by df; trap df = 1.

DISCUSSION

A total of 6 *Culicoides* species were captured during our studies in Cedar Key. In studies conducted near Yankeetown, FL, which is ca. 77 km southeast of Cedar Key, Lillie et al. (1987) captured 5 *Culicoides* species and Kline (1986) captured 21 species. In our study, it was determined that *C. furens* was more readily captured in all of the traps (91.6%), and the Liberty Plus trap was the best overall trap for the capture of *Culicoides* species.

In general, the Freedom and Liberty Plus traps were similar, with both using counterflow technology and identical baits. Although the appearances of the traps are somewhat different, the operating mechanism is similar. *Culicoides furens* is attracted to heat (Kline and Lemire 1995), CO<sub>2</sub> (Kline et al. 1990), and octenol (Ritchie et al. 1994). However, the Freedom trap bait-plume temperature ranges, depending on ambient temperature, from 33.34°C to 36.67°C. The Liberty Plus bait-plume temperature ranges, according to ambient temperature, from 33.34°C to 40.56°C. It

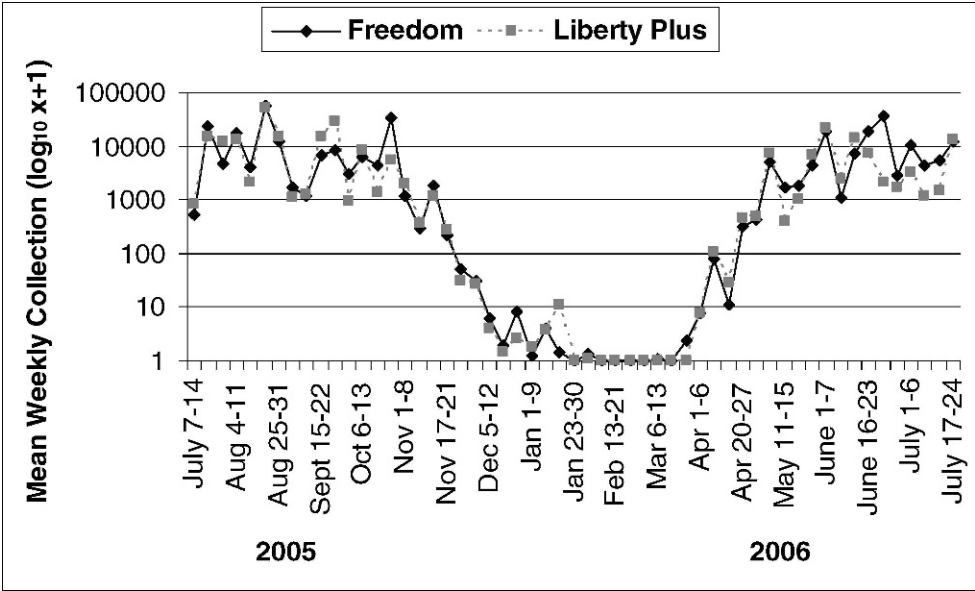


Fig. 3. Seasonal changes in abundance of *Culicoides furens* collected in Freedom<sup>®</sup> and Liberty Plus<sup>®</sup> traps in Rye Key, FL, from July 7, 2005, to July 24, 2006.

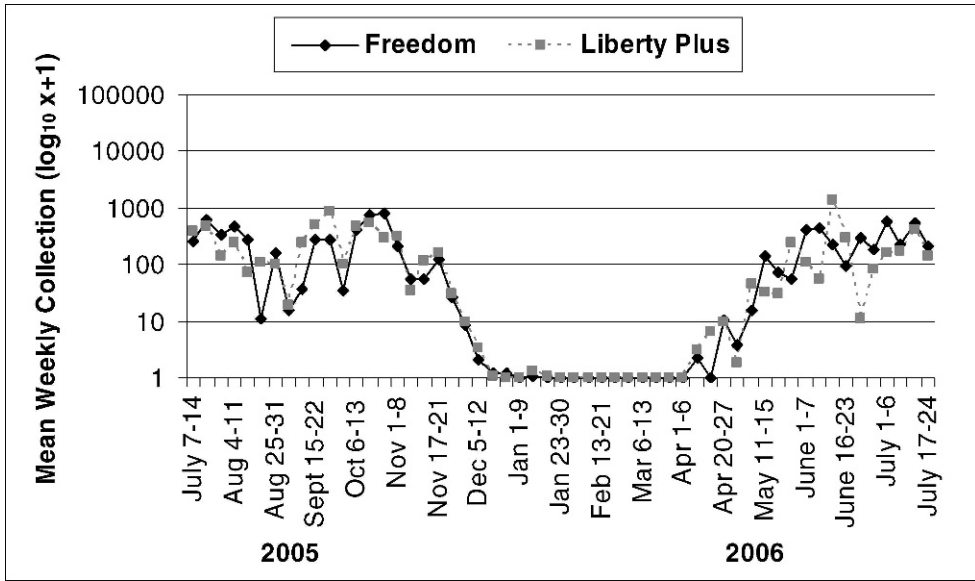


Fig. 4. Seasonal changes in abundance of *Culicoides barbosai* collected in Freedom® and Liberty Plus® traps in Rye Key, FL, from July 7, 2005, to July 24, 2006.

is unlikely that the small differences in the temperature ranges between traps are causing any differences in the *Culicoides* species captured. However, other factors may be involved, such as bait-plume delivery. It is possible that the Freedom and Liberty Plus are presenting the attractants differentially (Cooperband and Cardé 2006). This could affect a trap's ability to attract and capture host-seeking insects.

Furthermore, it is plausible that all of the species captured were not uniformly attracted to the traps used in this study. Kline et al. (1994) reported that *C. furens* was the only species of 3 major *Culicoides* species in the current study that were attracted to a combination of octenol bait and CO<sub>2</sub> in Sea Island, GA. However, they reported that all *Culicoides* captured were attracted to CO<sub>2</sub> alone. The combination of octenol

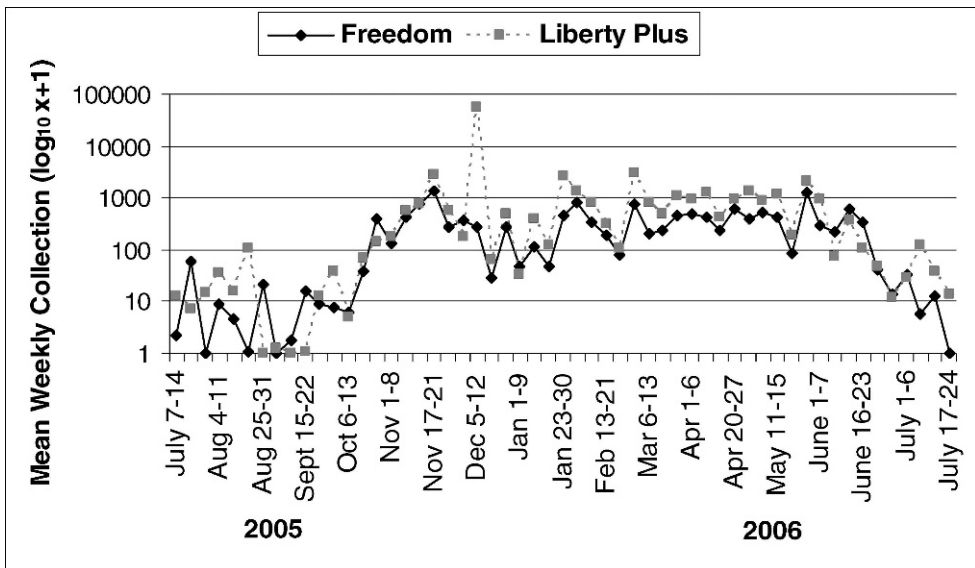


Fig. 5. Seasonal changes in abundance of *Culicoides mississippiensis* collected in Freedom® and Liberty Plus® traps in Rye Key, FL, from July 7, 2005, to July 24, 2006.

bait and CO<sub>2</sub> may be why *C. furens* was captured in such high numbers when compared with the other species captured in this study.

The optimal concentration of CO<sub>2</sub> for attraction of *Culicoides* species captured in this study is not known. Additionally, it is not known whether there are any differences in putatively pure CO<sub>2</sub> from a cylinder and CO<sub>2</sub> produced by burning propane. Cilek et al. (2003) used 500 ml/min of CO<sub>2</sub> when trapping adult *Culicoides* in the panhandle of Florida. Our study used traps that were producing CO<sub>2</sub> from 400 to 550 ml/min. The amount of CO<sub>2</sub> exhaled by humans is 250 to 300 ml/min (Reeves 1953, Schmidt-Nielsen 1975). Carbon dioxide levels emitted by Freedom and Liberty Plus traps are fixed and cannot be changed. The carbon dioxide range necessary for maximum attraction of *Culicoides* is related to the CO<sub>2</sub> produced by the preferred hosts of a particular *Culicoides* species; the larger the host animal, the more CO<sub>2</sub> will be exhaled. Many species of *Culicoides* feed primarily on mammals, whereas others feed preferentially on birds, reptiles, and amphibians. Those feeding on a certain class show size preferences within the class, such as a small versus a large host (Mullen 2002).

*Culicoides* spp. are known to fly for short distances and would most likely orient toward the trap closest to their emergence site. Mullen (2002) reported *Culicoides* being most abundant in close proximity to breeding sites. It has been demonstrated that certain *Culicoides* spp. fly from 3.5 km to 9.65 km (Lillie et al. 1985), but most *Culicoides* prefer to feed locally (Blanton and Wirth 1979, Day et al. 2001, Mullen 2002). Rye Key is surrounded by productive larval *Culicoides* habitat. However, it is also possible that *Culicoides* from other nearby larval habitats arrived in this study area and were collected in the traps. It is also possible that trap placement affected the numbers of *Culicoides* captured in certain traps on Rye Key. However, it is not likely because of the relatively small size of Rye Key and the relatively large number of traps available. In addition, there was habitat heterogeneity within the trapping site, making it difficult to place traps in favorable positions.

Different trapping methods and attractants used in previous studies likely account for some of the contrasts with species abundance and composition in our study. For instance, traps with lights and traps mounted on a truck (Lillie et al. 1987) may have sampled different components of the population. In addition, as a result of a multitude of environmental conditions, population levels of adult *Culicoides* vary from year to year (Wood and Kline 1989). The numbers of total *Culicoides* collected in our study were substantially more than those collected in previous studies, again, possibly because of differences between traps and environmental conditions.

On several occasions, *Culicoides* were observed resting on and around the traps, becoming active when a potential host approached the trap. It is not clear why *Culicoides* were attracted to the traps but did not enter. One possibility is confusion resulting from the bait-plume delivery. Additionally, while there was no evidence of the collection nets being filled to maximum capacity during this study, the suction from the fans may have decreased as the collection nets filled with insects, allowing some *Culicoides* to evade capture.

There were some problems with long-term efficiency of the Freedom traps. Six months after the study began, the metal power packs where the catalytic combustion of propane occurs had to be replaced on all 10 traps. In addition, it was common for *Culicoides* to be found inside the traps but outside of the collection nets. This is not a concern for the consumer, but for research, the insects had to be vacuumed and added to each collection to maximize accuracy. Overall, the Liberty Plus was the more reliable trap. An additional consideration for the average homeowner is that the Liberty Plus trap is less cumbersome to transport than the Freedom trap.

In general, the seasonal patterns of all *Culicoides* captured in this study coincide with previous research; however, the seasonal abundance for *C. mississippiensis* differed from studies in or near Yankeetown, FL. Disparity in seasonal abundance may be caused by differences in habitat structure or types of traps used for collection. While similar species of marsh vegetation are found in both Cedar Key and Yankeetown, the structure of the habitat may play an important role in population levels.

In our study, the seasonal abundance patterns of *C. furens* and *C. barbosai* were similar and populations were higher in the warmer months, being most abundant from May through October and declining in November (Figs. 3, 5). In Yankeetown, FL, Kline (1986) reported that *C. furens* and *C. barbosai* populations captured in New Jersey light and emergence traps appeared in early April and continued through September (sometimes with a lull in activity in early July). *Culicoides barbosai* was captured in much smaller numbers than *C. furens*. Furthermore, in Lee County, FL, Kline and Roberts (1982), using New Jersey light traps, found similar seasonal trends between the 2 species, with *C. furens* being the more abundant species collected. Near Yankeetown, FL, Lillie et al. (1987), using a vehicle-mounted insect trap, reported that *C. furens* was active from March through November. They also reported that *C. barbosai* was less abundant than *C. furens*; however in contrast to our study, the seasonal fluctuations of these 2 species did not coincide.

In our study, *C. mississippiensis* was collected throughout the year, with the greatest abundance

during the cooler months from November through May (Fig. 4). However, even during its period of peak abundance, this species was not as numerous as *C. furens*. In Lee County, FL, Kline and Roberts (1982) captured *C. mississippiensis* infrequently. Near Yankeetown, FL, Lillie et al. (1987) reported that *C. mississippiensis* was the most abundant species captured and present throughout the entire year with increased abundance during the cooler months. Kline (1986) reported *C. mississippiensis* peaked in March, May, and again in September and November, with the lowest collections in February. In contrast, in our study, February was the month with greatest collections of *C. mississippiensis*. Throughout our study, *C. mississippiensis* was consistently captured in larger numbers in the Liberty Plus trap, explaining the lack of trap by month interaction.

Species seasonal effects and trap preference can dramatically influence the number of *Culicoides* captured in traps. There is some variation in our trap captures because of circumstances beyond our control, such as trap failures, hurricanes, and holidays. Although these circumstances were minimized, they could not be eliminated. However, we feel that the number of trap nights in this study (101–310 nights per month) provided a reliable representation of the species captured in Cedar Key.

Because of state and federal regulations restricting pesticide use and habitat alteration, removal trapping has become the method of choice for *Culicoides* and mosquito management. Areas with known *C. furens* infestations could benefit from the knowledge gained in this study. This study provides a solid framework to build upon in the future. It may be possible to control *Culicoides* by continuous trapping. However, understanding the seasonal abundance of specific species will allow for the targeting of months when those species are most abundant, so preemptive strikes can be waged on the 1st broods of the year. This will decrease the control costs and increase the efficiency of the operation. Ultimately, more effective control of *Culicoides* will entail the development of an integrated pest management program using multiple, consistent control strategies to relieve the biting pressure of these pestiferous biting midges.

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